

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
APPLICATION FOR PATENT

MODULAR ICP TORCH ASSEMBLY

Inventors: Albert R. DePetrillo;
Craig R. Heden; and
Robert M. McGuire.

FIELD OF THE INVENTION

The present invention generally relates to inductively coupled plasma ("ICP") torches and in particular, to a modular ICP torch assembly.

BACKGROUND OF THE INVENTION

ICP torches have a long history in semiconductor processing and spectrographic applications. Commonly used ICP torches, however, are not easy to disassemble, thereby making repair and maintenance of the torch difficult. This results in undesirable equipment down time that, in a manufacturing environment, can significantly reduce production volume and increase per unit costs. Further, different applications or processing requirements often require different ICP torch configurations, component dimensions, and/or component materials. Consequently, multiple ICP torches may be used in the manufacturing or a test environment, thereby increasing manufacturing and/or test costs. Still further, coolant tubes that are fused in ICP torches to their plasma chambers to cool them down are subject to cracking and consequently, leaking of the coolant into the plasma chambers.

OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an ICP torch that is easily assembled and disassembled to minimize equipment down time.

5 Another object is to provide an ICP torch that is modular in design so that component parts can be mixed and matched to suit their application use.

 Another object is to provide an ICP torch that includes a coolant mechanism that avoids contamination of
10 the plasma chamber upon failure, and is easily replaced.

 Still another object is to provide an ICP torch that is reliable, efficient, high performing, and cost effective.

 These and additional objects are accomplished by
15 the various aspects of the present invention, wherein briefly stated, one aspect is a modular ICP torch assembly comprising a tubular plasma chamber, a tubular jacket, and detachable connector units. The detachable connector units hold the tubular plasma chamber concentrically within the
20 tubular jacket so as to define an annular chamber between the two, and provide a flow of coolant through the annular chamber to cool the outer surface of the tubular plasma chamber.

 Another aspect is a modular ICP torch assembly
25 comprising a tubular plasma chamber, a rear connector unit, and an inductive coupling member. The rear connector unit is positioned and detachably held at a rear end of the tubular plasma chamber to provide a flow of material into the tubular plasma chamber. The inductive coupling member
30 is for inductively applying energy to the material flowing

through the tubular plasma chamber in order to produce and sustain plasma in the chamber.

Still another aspect is a modular inductively coupled plasma torch assembly. A rear connector unit is positioned and detachably held at a rear end of a tubular plasma chamber to provide a flow of material into it. Detachable connector units are positioned on opposite ends of a tubular jacket, and hold the tubular plasma chamber concentrically within the tubular jacket so as to define an annular chamber between the two tubes. An inductor coil is disposed concentrically around the tubular jacket and energized so as to generate plasma from the material flowing in the tubular plasma chamber. To cool the tubular plasma chamber, coolant flows through the annular chamber using inlet and outlet ports in the detachable connector units for such flow of coolant.

Additional objects, features and advantages of the various aspects of the present invention will become apparent from the following description of its preferred embodiment, which description should be taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a side view of a modular ICP torch assembly utilizing aspects of the present invention.

FIG. 2 illustrates a top view of a detachable rear connector unit included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 3 illustrates a top view of a detachable front connector unit included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 4 illustrates a side view of a detachable
5 front connector unit included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 5 illustrates a side view of a detachable jacket connector unit included in a modular ICP torch assembly, utilizing aspects of the present invention.

10 **FIG. 6** illustrates a front view of a cinch nut included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 7 illustrates a side view of a cinch nut
15 included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 8 illustrates a front view of a seal ring included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 9 illustrates a side view of a seal ring
20 included in a modular ICP torch assembly, utilizing aspects of the present invention.

FIG. 10 illustrates a cross-sectional view of one end of a detachable connector, utilizing aspects of the present invention.

25 **FIG. 11** illustrates a side view of an alternative modular ICP torch assembly utilizing aspects of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 illustrates a side view of a modular ICP torch assembly 100 including a tubular plasma chamber 101, a tubular jacket 102 that is disposed concentrically around the tubular plasma chamber 101, and an inductor coil 103 that is disposed concentrically around the tubular jacket 102. The induction coil 103 preferably has a coil diameter that is slightly larger than the outer diameter of the tubular jacket 102 so that the tubular jacket 102 can fit comfortably, yet snugly in the induction coil 103. On the other hand, the tubular jacket 102 preferably has an inner diameter that is significantly larger than the outer diameter of the tubular plasma chamber 101 so that an annular chamber sufficient in size to accommodate desired coolant volume flow rate is defined between the inner surface of the tubular jacket 102 and the outer surface of the tubular plasma chamber 101.

In operation, the inductor coil 103 is energized while source material commonly in gaseous form flows by the induced field to generate plasma in the tubular plasma chamber 101. The composition and form of such material are chosen according to the application of the ICP torch assembly 100. Although an inductor coil is shown in this example for inductively applying energy to the source material, other means for doing so are also contemplated to be within the scope of the present invention. Additional details on the operation of and application examples for an ICP torch are described in commonly owned United States Patent Application Serial Number 10/404,216 entitled "Remote ICP Torch for Semiconductor Processing," which is incorporated herein by this reference.

Since the generation of plasma in the tubular plasma chamber 101 causes the tubular plasma chamber 101 to heat up, coolant is passed through the annular chamber defined between the concentrically aligned tubular plasma chamber 101 and tubular jacket 102 to cool the outer surface of the tubular plasma chamber 101. The coolant may be in gaseous or liquid form, and may flow at various flow rates according to the application of the ICP torch assembly 100. As an example, deionized water is a commonly used coolant in ICP torch applications.

Also included in the modular ICP torch assembly 100 are several detachable connector units. These units serve to not only hold the various components of the modular ICP torch assembly 100 together, but they also provide inlet ports for source material to flow into the tubular plasma chamber 101, and inlet and outlet ports for the coolant to flow into and out of the annular chamber defined between the tubular jacket 102 and the tubular plasma chamber 101. Note that FIG. 1 only shows simplified versions of these detachable connector units. Therefore, FIGS. 2~10 are provided for a better understanding of their construction, assembly and operation.

A detachable rear connector unit includes a rear connector 201 whose top view is shown in detail in FIG. 2. As shown in more detail in FIG. 10, the rear connector 201 has an open end 211 through which a rear end of the tubular plasma chamber 101 is positioned and held in place by a cinch nut 203, a seal ring 204, a compressible O-ring 205, and slip washer ring 206. The cinch nut 203 is shown in more detail for front and side views respectively in FIGS. 6 and 7, and the seal ring 204 is shown in more detail for

front and side views respectively in **FIGS. 8** and **9**. The O-ring **205** and the slip washer ring **206** are simply well known "O" shaped components and therefore, are not separately shown in detail.

5 The cinch nut **203**, the slip washer ring **206**, the seal ring **204**, and the O-ring **205** are each placed in that order around the tubular plasma chamber **101**, and slid down part way along its outer surface to get temporarily out of the way. The tubular plasma chamber **101** is then
10 inserted into the open end **211** of the rear connector **201** until it nears or stops against an annular rear wall **223** of an outer cylindrical cavity **214** of the rear connector **201**. The diameter of the outer cylindrical cavity **214** is preferably approximately the same as that of the tubular
15 plasma chamber **101** so that the tubular plasma chamber **101** fits snugly in the outer cylindrical cavity **214** with minimal lateral movement when inserted therein. The O-ring **205** is then slid back down the outer surface of the tubular plasma chamber **101** until it stops against a tapered
20 wall **212** of the rear connector **201**. Likewise, the seal ring **204**, slip washer ring **206**, and cinch nut **203** are also slid back down along the outer surface of the tubular plasma chamber **101** until inner threads **604** of the cinch nut **203** engage outer threads **213** of the rear connector **201**.

25 The cinch nut **203** is then screwed into the outer threading of the connector **201** so the seal ring **204** is pushed into compressing the O-ring **205** against the tapered wall **212** of the rear connector **201**, thereby generating compression forces within the thus compressed O-ring **205**
30 that radiate outward from the O-ring **205** and against the seal ring **204**, the tapered wall **212**, and the outer surface

of the tubular plasma chamber 101, so as to securely hold the rear connector 201 in place against the tubular plasma chamber 101. The slip washer ring 206 placed between the seal ring 204 and the cinch nut 203 serves to inhibit
5 torque applied to the cinch nut 203 (e.g., for screwing it into the outer threading 213 of the rear connector 201) from being transferred to the O-ring 205.

The rear connector 201 also has two inlet ports 202 and 220 for receiving material flows from external
10 material sources and providing the material flows into the tubular plasma chamber 101. The inlet ports 202 and 220 utilize compression type fittings in order to accommodate hoses connected at opposite ends to the external material sources. The materials provided at inlet ports 202 and 220
15 may be different materials or the same material according to the application of the modular ICP torch 100. Materials entering through inlet ports 202 and 220 first enter an inner cylindrical cavity 215 before exiting through a circular opening 224 into the interior of the tubular
20 plasma chamber 101 which is positioned in the outer cylindrical cavity 214 through open end 211 of the rear connector 201. The width of the annular wall 223 used as a stop for the tubular plasma chamber 101 is determined by the difference in diameters of the circular opening 224 and
25 the outer cylindrical cavity 214.

A sapphire window 225 prevents the flows of materials from exiting the inner cavity 215 through an opening 221 included in the back of the rear connector 201. The internally threaded opening 221 is included in the back
30 of the rear connector 201 so that an optical emission spectrometer or other metrology system may be attached to

the modular ICP torch 100. The optical emission spectrometer views the plasma generated in the tubular plasma chamber 101 in this case through the sapphire window 225.

5 A detachable front connector unit includes a front connector 301 whose top view is shown in detail in FIG. 3 and side view shown in detail in FIG. 4. The front connector 301 has a first open end 314 adapted to receive a front end of the tubular plasma chamber 101, and a second
10 open end 320 adapted to receive tubing 104 that is fluidically coupled, for example, to a processing chamber for processing at least one semiconductor wafer. The tubular plasma chamber 101 is positioned and held in place with respect to the front connector 301 by a cinch nut 303,
15 a seal ring 304, a compressible O-ring 305, and slip washer ring (not shown), in much the same manner as described in reference to their counterparts in the rear connector unit as previously described. Likewise, the tubing 104 is positioned and held in place with respect to the front
20 connector 301 by a cinch nut 306, a seal ring 307, a compressible O-ring 308, and slip washer ring (not shown), also in much the same manner as described in reference to their counterparts in the rear connector unit as previously described.

25 A first cylindrical cavity 317 in the front connector 301 receives the tubular plasma chamber 101 through the first open end 314, and a second cylindrical cavity 319 receives the tubing 104 through the second open end 320. An inner cylindrical cavity 318 fluidically
30 couples the first and second cylindrical cavities 317 and 319 so that plasma generated material flowing into the

first open end **314** passes out of the second open end **320**.
The diameter of the first cylindrical cavity **314** is
preferably approximately the same as that of the tubular
plasma chamber **101** so that the tubular plasma chamber **101**
5 fits snugly in the first cylindrical cavity **314** with
minimal lateral movement when inserted therein. The
diameter of the first cylindrical cavity **314** is also
preferably larger than that of the inner cylindrical cavity
318 by an amount sufficient to define an annular wall at
10 the rear of the first cylindrical cavity **317** that serves as
a stop for the tubular plasma chamber **101**, as well as
providing sufficient thickness to accommodate flared inlet
channels **312** and **322**. The second cylindrical cavity **319** is
also larger than the diameter of the inner cylindrical
15 cavity **318** by an amount sufficient to define an annular
wall at the rear of the second cylindrical cavity **319** that
serves as a stop for the tubing **104**. The diameter of the
second cylindrical cavity **319** is smaller than that of the
first cylindrical cavity **317** in this example so as to
20 increase the flow rate of plasma generated material going
into the tubing **104**.

The front connector **301** has two inlet ports **302**
and **313** adapted, for example, for compression fittings or
other hose coupling mechanism for receiving material flows
25 from external material sources and directing the material
flows into the tubular plasma chamber **101** through flared
inlet channels **312** and **322** so as to flow back towards, and
in some applications be part of, the generation of plasma
in the tubular plasma chamber **101**. The inlet channels **312**
30 and **322** are flared so that their material flows are at
angles from the axis of the tubular plasma chamber **101**,

thus resulting in good material distribution in the tubular plasma chamber 101.

Those familiar with the art of ICP torches will appreciate that in addition to the embodiments described
5 herein, other front connector designs may also be used in practicing the present invention, including, for example, those that directly bolt the tubular plasma chamber 101 to a processing chamber such as used for processing at least one semiconductor wafer.

10 In applications where material flow through the front connector unit is not necessary, a modified version of the front connector 301 may be employed. In the modified version, inlet ports 302 and 313 and their corresponding flared inlet channels 312 and 322 are
15 eliminated. Construction of the first and second open ends 314 and 320 and their corresponding cylindrical cavities 317 and 319 remain the same, so that the same tubular plasma chamber 101, tubing 104, cinch nuts 303 and 306, seal rings 304 and 307, O-rings 305 and 308, and slip
20 washer rings can be used with the modified version of the front connector unit. Consequently, easy conversion from one version of the modular ICP torch assembly to another is facilitated as applications for the modular ICP torch assembly change.

25 In applications where cooling of the tubular plasma chamber 101 is not required, then the modular ICP torch assembly 100 is assembled by first inserting the tubular plasma chamber 101 into the induction coil 103, then attaching the rear and front connector units, in
30 either order, as described above. The tubular jacket 102 and corresponding pair of connection units for attaching

the tubular jacket 102 to the tubular plasma chamber 101 are not included in the assembly.

In applications where cooling of the tubular plasma chamber 101 is required, however, then the module ICP torch assembly 100 is assembled by inserting the tubular plasma chamber 101 into the tubular jacket 102, inserting the tubular jacket 102 into the induction coil 103, attaching a pair of connection units at opposing ends of the tubular jacket 102 so as to attach the tubular jacket 102 to the tubular plasma chamber 101, and attaching the rear and front connector units to the ends of the tubular plasma chamber 101 as described above.

The pair of connection units that attach the tubular jacket 102 to the tubular plasma chamber 101 are referred to as detachable first and second connection units. The detachable first connection unit includes a first connector 401 whose side view is shown in detail in FIG. 5. It has a large diameter end 417 through which the tubular jacket 102 is inserted and held in a large cylindrical cavity 420, and a small diameter end 411 through which the tubular plasma chamber 101 passes through so as to fill up a small cylindrical cavity 414. The diameter of the large cylindrical cavity 420 is approximately the same as that of the tubular jacket 102 so that the tubular jacket 102 fits snugly in the large cylindrical cavity 420 with minimal lateral movement when inserted therein. Likewise, the diameter of the small cylindrical cavity 414 is approximately the same as that of the tubular plasma chamber 101 so that the tubular plasma chamber 101 fits snugly in the small cylindrical cavity 414 with minimal lateral movement when inserted therein.

To assemble the first connection unit, a cinch nut 403, a slip washer ring (not shown), a seal ring 407, and a compressible O-ring 405 are each placed in that order around the tubular jacket 102, and slid part way down its surface to get temporarily out of the way. The tubular jacket 102 is then inserted into the large diameter end 417 of the first connector 401 until it stops against an annular rear wall 421 of the large cylindrical cavity 420. The O-ring 405 is then slid back down the outer surface of the tubular jacket 102 until it nears or stops against a tapered wall 419 of the large diameter end 417 of the first connector 401. Likewise, the seal ring 407, slip washer ring (not shown), and cinch nut 403 are also slid back down along the outer surface of the tubular jacket 102 until inner threads of the cinch nut 403 engage outer threads 418 of the first connector 401.

The cinch nut 403 is then screwed into the outer threading of the first connector 401 so that the seal ring 407 is pushed in compressing the O-ring 405 against the tapered wall 419 of the first connector 401, thereby generating compression forces within the thus compressed O-ring 405 that radiate outward from the O-ring 405 and against the seal ring 407, the tapered wall 419, and the outer surface of the tubular jacket 102.

A compressible O-ring 406, a seal ring 408, a slip washer ring (not shown), and a cinch nut 404 are each placed in that order around the exposed rear end of the tubular plasma chamber 101, and slid down its surface towards the small diameter end 411 of the first connector 401 until the O-ring 406 nears or stops against a tapered wall 413 of the small diameter end 411 of the first

connector 401. The cinch nut 404 is then screwed into the outer threading 412 of the first connector 401 so the seal ring 408 is pushed into compressing the O-ring 406 against the tapered wall 412, thereby generating compression forces within the thus compressed O-ring 406 that radiate outward from the O-ring 406 and against the seal ring 408, the tapered wall 412, and the outer surface of the tubular plasma chamber 101, so as to securely hold the first connector 401 against the tubular jacket 102 on one end and the tubular plasma chamber 101 on the other end of the first connector 401.

The cinch nut 404, seal ring 408, O-ring 406, and corresponding slip washer ring are identically sized and constructed as their respective counterparts as described in reference to FIGS. 1, 2, and 6~9. The cinch nut 403, seal ring 407, O-ring 405, and corresponding slip washer ring, on the other hand, are each shaped as, but larger their respective counterparts as described in reference to FIGS. 1, 2, and 6~9, since these components are adapted for the larger diameter of the tubular jacket 102.

The detachable second connector unit is similarly constructed as the first detachable connector unit, and attached at the opposite end of the tubular jacket 102 to the tubular plasma chamber 101 in the same manner as described in reference to the first detachable connector unit. After attaching both ends of the tubular jacket 102 to the tubular plasma chamber 101, the detachable rear and front connector units are then attached to the tubular plasma chamber 101 as previously described.

As previously explained, coolant for cooling the tubular plasma chamber 101 is passed over the outer surface

of tubular plasma chamber 101 through the annular chamber defined between the concentrically aligned tubular jacket 102 and tubular plasma chamber 101. The coolant, which is provided from an external coolant source, enters an inlet
5 port 402 in the first connector 401 of the detachable first connector unit, flows through an opening 416 of the first connector 401 into the annular chamber, exits the annular chamber on the opposite side of the tubular jacket 102 though an opening in a second connector 501 of the
10 detachable second connector unit, and returns to the external coolant source through an outlet port 502 of the second connector 501. Although the port 402 is referred to as an inlet port and the port 502 is referred to as an outlet port in this example, it is to be appreciated that
15 if the coolant were to flow in the opposite direction, then the port 502 would serve as an inlet port and the port 402 would serve as an outlet port in that case. Therefore, the ports 402 and 502 are referred to as respectively being inlet and outlet ports for convenience only and such
20 terminology should not be used to place any limitation on their actual or claimed use.

When the pressure created by the flow of coolant becomes very large, it may be advantageous to provide additional support to hold the tubular jacket 102 in place.
25 **FIG. 11** illustrates a top view of a second embodiment of a modular ICP torch assembly wherein a supporting rod 903 helps hold the tubular jacket 102 in place by supporting the first and second connectors from being forced apart by the coolant pressure. The supporting rod 903 has threaded
30 ends which are inserted into mechanical supports 901 and 902 respectively integrated on the first and second

connectors 401 and 501. Nuts 904 and 905 screwed into the threaded ends of the supporting rod 903 then hold the supporting rod 903 in place between the mechanical supports 901 and 902 to prevent the first and second connectors 401 and 501 from being forced apart due to the large coolant pressure. For additional and balanced support, a second supporting rod may be installed in the same manner on an opposite side of the modular ICP torch assembly.

Although the various aspects of the present invention have been described with respect to a preferred embodiment, it will be understood that the invention is entitled to full protection within the full scope of the appended claims.